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# Measurements of the laminar burning velocities of ethanol-water-air flames





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## Introduction

Next to the use of fossil fuels, other fuels are increasingly becoming the focus of public discussion. Reasons for the search for alternatives are the limited crude oil reserves, but also the environmental pollution and emissions that occur during the combustion of mineral oil products and their additives. An alternative to diesel or gasoline offer bio-alcohols such as ethanol. Ethanol, such as other alcohols, absorbs water from the air contained moisture. To understand the impact of water content in ethanol, either due to long term storage or due to water injection strategies during combustion, extensive laminar flame velocity ( $S_L$ ) experiments have been performed.

#### **Results and discussion**

Figure 2 compares the present data including error bars with published data and shows good agreement. The overall accuracy for  $S_L$  was around  $\pm 1$  cm/s. At lean and near stoichiometric conditions the obtained  $S_L$  is slightly faster in comparison to other experiments.





#### **Experimental setup**

The laminar burning velocity of ethanol-water-air flames at atmospheric pressure and initial gas temperatures of T = 358 K was measured with the heat flux method. The mixture of ethanol-water-air contained 0%, 10%, 20%, 30% and 40% water by mole and the equivalence ratio ( $\phi$ ) range was varied from 0.7 to 1.4.



Figure 2: Laminar burning velocity of premixed ethanol-air flames at T = 358 K and atmospheric pressure in comparison with published experimental data [9–12].

Figure 3: Laminar burning velocity of premixed ethanol-water-air flames at T = 358 K and atmospheric pressure in comparison to the simulation data of Konnov et al. [7]. Symbols: experiments, lines: modeling.

The S<sub>L</sub> measured by Sileghem et al. [9] agrees very good for lean and rich mixtures with the present measurements. At  $\phi = 1.3$  the present data found to be close to the data of Dirrenberger et al. [10] and Sileghem et al. [9] with a difference below 1 cm/s. The S<sub>L</sub> of Liao et al. [12] are generally 6 cm/s slower at all conditions than the presented results. It should be noted that Liao et al. [12] used a combustion bomb to determine the S<sub>L</sub>.

The S<sub>L</sub> obtained along with their uncertainties are compared against the predictions of three models seen in Figure 3 to Figure 5. It is seen that the experimental S<sub>L</sub> for ethanol-water-air mixtures decrease with increasing the water content 10 - 40%.

## Modelling

The experimental data were simulated using three kinetic models: Model of **Moshammer et al. [1]** based on a series of previous developments [2–4]. The model of **Shrestha et al. [5]** focused on the oxidation of methanol and ethanol and their fuel interaction with NO<sub>x</sub> chemistry. The modelling of both were performed with LOGEresearch [6]. The last model, a mechanism of **Konnov and coworkers [7]** based on the Konnov mechanism version 0.6 [8] and include extensive updates and validation for methanol. The numerical calculations for this model were conducted with CHEMKIN-PRO software package.





Figure 4: Laminar burning velocity of premixed ethanol-water-air flames at T = 358 K and atmospheric pressure in comparison to the simulation data of Moshammer et al. [1]. Symbols: experiments, lines: modeling.

Figure 5: Laminar burning velocity of premixed ethanol-water-air flames at T = 358 K and atmospheric pressure in comparison to the simulation data of Shrestha et al. [5]. Symbols: experiments, lines: modeling.

General the experimental data for  $S_L$  show a better agreement with the model of Konnov et al. [7], seen in Figure 3. The model of Konnov et al. [7] leads to a slight underestimation of the  $S_L$  in particular at rich conditions by below 2 cm/s. A very close agreement is observed for lean mixtures.

Figure 4 displays the experimental results for ethanol-water-air flames, which are in good agreement with the model [1] at lean conditions with a underprediction of around 3 cm/s. For the dilution of 10 % water the model tends to underpredict the experimental  $S_L$  by around 10 cm/s. Finally, Figure 5 compares the present data with the model of Shrestha et al. [5]. This model [5] predicts the experimental results very well at rich mixtures with the difference in  $S_L$  being around 2 cm/s.

#### Conclusions

The S<sub>L</sub> measured by Sileghem et al. [9] and Dirrenberger et al. [10] shows a close match with present experiments, which were obtained using the same method. The kinetic model of the group of Konnov et al. [7] agrees best with present data. The model of Shrestha et al. [5] displays a good agreement at lean and rich conditions with an underprediction at stoichiometric mixtures.

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